Optical Variability and Bottom Classification in Turbid Waters: Phase III

Kendall L. Carder
David K. Costello
College of Marine Science
University of South Florida
St. Petersburg, FL 33701-5016
phone: (727) 553-3952   fax: (727) 553-3918   email: kcarder@monty.marine.usf.edu

LONG-TERM GOALS

Real-time determination of the optical and bathymetric climate available for operation of various Navy and Coast Guard assets in the coastal zone using a mixture of AUV, ROV, surface-vessel, fixed moorings/towers, and air/space-borne observational assets. This includes advanced heat-budget modeling applicable to coastal regions, methods for early detection of *K. brevis* (red-tide) and other algal blooms, remote determination of optical properties (absorption and scattering) of the water, harmful algal blooms, depth and bottom albedo. These provide model inputs and validation data for predicting visibility and the performance of optical systems as well as heat budget and primary production models, useful in asset selection for Homeland Security operations.

OBJECTIVES

The development of optical methodologies valid for Case II coastal waters for the remote determination of water and bottom optical properties including visibility, water and bottom optical absorption, algal concentrations, bathymetry, bottom albedo, vegetation cover, and bottom structure are being pursued. These include interpretation of hyperspectral, high-resolution imagery from aircraft and satellites, development and deployment of suites of small instruments on remotely operated and autonomous underwater vehicles (ROVs, AUVs) and a multi-disciplinary network of moored sensors. Data are used in development/application of radiative transfer models and algorithms for predicting optical properties and extracting information from the remote data. Effects of vertical structure in the optical properties (e.g. river plumes, suspended sediments) and turbidity must be recognized for the data retrievals to be accurate, and the instruments and methodologies necessary to quantify such structure are being developed and utilized on underwater vehicles and moorings.

A focus for our work this year is in direct response to the September 11 attacks on the United States and the call for increased attention to Homeland Security with an emphasis on Port Security. We have accelerated our efforts toward the quantification of performance parameters for underwater imaging systems and for now-casting the optical properties of the water column at scales appropriate to application in Homeland Security strategies.

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Optical Variability and Bottom Classification in Turbid Waters: Phase III**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **College of Marine Science,,University of South Florida,,St. Petersburg,,FL,33701**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Real-time determination of the optical and bathymetric climate available for operation of various Navy and Coast Guard assets in the coastal zone using a mixture of AUV, ROV, surface-vessel, fixed moorings/towers, and air/space-borne observational assets. This includes advanced heat-budget modeling applicable to coastal regions, methods for early detection of K. brevis (red-tide) and other algal blooms, remote determination of optical properties (absorption and scattering) of the water, harmful algal blooms, depth and bottom albedo. These provide model inputs and validation data for predicting visibility and the performance of optical systems as well as heat budget and primary production models, useful in asset selection for Homeland Security operations.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

APPROACH

We have developed models for inverting hyperspectral data from air- and space-borne sensors in vertically homogeneous waters to estimate absorption, back-scattering, and beam-attenuation coefficients, as well as bathymetry and bottom albedo (see PUBLICATIONS). We have also presented methodologies for advanced coastal-water heat budget modeling (Warrior et al. 2002) and early detection of red-tide and other algal blooms (Cannizaro et al. 2003). These can be used as initial or boundary conditions for heat-budget, primary production and visibility models and to predict where certain mine-counter-measure assets can productively be deployed or not.

Water clarity, bathymetry, and bottom albedo are critical variables affecting optical searches for objects in the water column or on the bottom. Object contrast with the background optical field or its 3-dimensional shape can be used in object-classification schemes. We are using elastic and inelastic scattering and active and passive imaging systems and are evaluating how system performance degrades with increased turbidity, range, and optical structure (e.g. layers) over a variety of bottom types and beneath underwater structures, e.g. ship hulls (Hou et al, 2002: Reinersman and Carder, 2002; 2003).

We have developed several optical packages for deployment on ROVs and AUVs to measure the optical properties of the water column and bottom to provide an assessment of the accuracy of the model assumptions and retrieval values from air-borne sensors, and we have deployed these as part of the CoBOP and HYCODE field activities. Several of these [e.g. Bottom Classification and Albedo Package, BCAP, Real-Time Ocean Bottom Optical Topographer, (ROBOT), and the Mobile Inspection Platform (MIP)] have been developed and tested on ROVs or AUVs including our ROSEBUD remotely operated vehicle (ROV), the Ocean Explorer class autonomous underwater vehicles, and USF's Center for Ocean Technology (COT) ROVEX vehicle (Carder et al., 2001; Costello and Carder, 1997; Costello et al., 1998a, 1998b; Renadette et al., 1997, 1998).

WORK COMPLETED

Oceanography is inherently a multi-disciplinary science and our group is a team of oceanographers dedicated to developing optical methodologies that address real-world applications. These efforts require acquisition of extensive field data (above and below the surface) and extensive modeling. Analysis and comprehensive interpretation of field data and model results requires us to address physical, biological, chemical, and geological processes which affect water optics. The range and success of our work, then, is most directly presented via a list of 23 publications (14 refereed) produced by our group in 2002 and 2003. Please refer to the **PUBLICATIONS** section below.

RESULTS

Elastic and inelastic 3-D images for inspection of ship hulls were acquired by inverting the ROBOT system (a prototype for the Mobile Inspection Platform) on our ROSEBUD ROV in the relatively turbid water (c532 ≈ 3.0/m) of Tampa Bay. 2-Way maximum ranges of 18 e-folding lengths were determined in the elastic mode and 12 e-folding lengths in the fluorescence mode using the Xybion intensified camera as a receiver. Fluorescence-mode imagery would be most useful in highly scattering waters because of the elimination of on-line path radiance. The Fluorescence mode would also be useful, for example, in detecting a recently-attached object (e.g. a limpet mine) on a ship hull

since the recent object would not have sufficient algal growth to fluoresce. Figure 1 shows a 3-dimensional fluorescence image acquired during the Submerged Target Aging Experiment (Stage). The (inverted) image is of the hull of a small boat to which a pair of targets were added each week. Note that the targets were painted flat black and would not necessarily reflect highly enough to be visualized in a reflective mode.
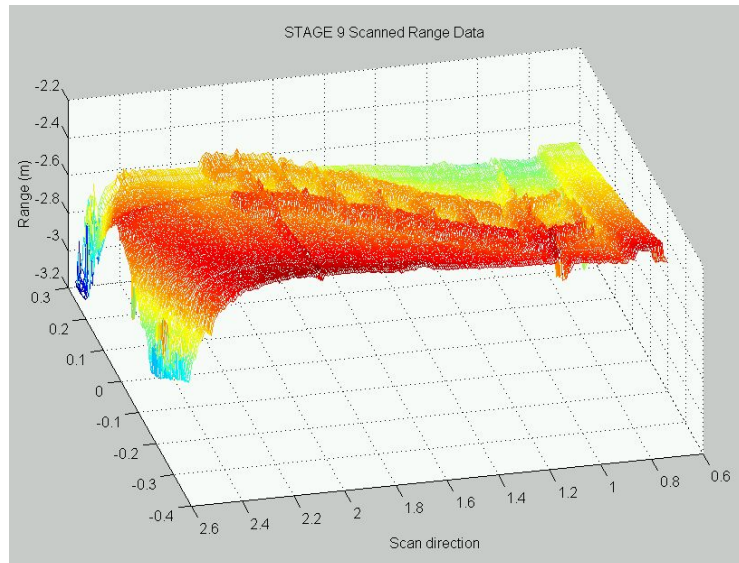

Figure 1. A 3-dimensional laser-line image acquired in the fluorescence mode. Note that the image is possible because of fluorescence of algal scum on the boat hull and aged targets. The targets consisted of sections of PVC pipe that were painted flat black and not likely to be visualized in a reflective mode.

Bathymetry and bottom-albedo maps (Fig. 2) were derived from PHILLS hyperspectral radiometer images of turbid Charlotte Harbor. Both are needed for 2 and 3-D models of the light field for ports and waterways and beneath ships (see Reinersman and Carder, 2003) and are useful indicators of hazards to navigation.

Red-tide blooms with chlorophyll_a concentrations greater than 2-3 mg/m^3 or 10,000-20,000 cells/liter can be discriminated and quantified from space-craft or aircraft ocean-color data by both chlorophyll-specific backscattering and fluorescence (Cannizzaro et al. 2003). Concentrations as high as 140 mg/m^3 were quantified by fluorometric remote sensing.

Ship-shadow measurements were acquired in the field along with IOP and AOP measurements as well as bottom albedo to validate the results from a structured light model (HyMOM, Reinersman and Carder, 2003). Initial analysis shows good agreement between field measurements and model results.

IMPACT/APPLICATIONS

In last year's report, we discussed solar-stimulated fluorescence imagery of the bottom. This type of passive, off-band imagery can be acquired in any area where the depth is sufficient to effectively quench 685 nm reflected solar radiation and where blue-green radiation penetrates sufficiently to stimulate 685 nm fluorescence to a level which allows image formation by the sensor. The significance is two-fold: first, since the bottom is the source, the imagery acquired is free from the

backscattered path radiance generally associated with contrast degradation in underwater imagery second, animals and man-made objects do not, generally, fluoresce at 685 nm. Given the appropriate environmental parameters, this makes possible the visualization of bottom objects that may not be apparent using either active or passive reflection (elastic) imaging techniques. Applicability ranges from assessment of the standing stock of sponges to underwater mine detection.

This year we found that laser-line imagery of ship hulls at 532nm will excite fluorescence of algal scum on the hulls for easy observation with intensified cameras at 685nm. Recent ship-bottom modifications will display a differing fluorescence signature from the undisturbed hull. The technique is also applicable to vertical underwater structures (e.g. pilings, sea walls) that are of interest in Port Security.
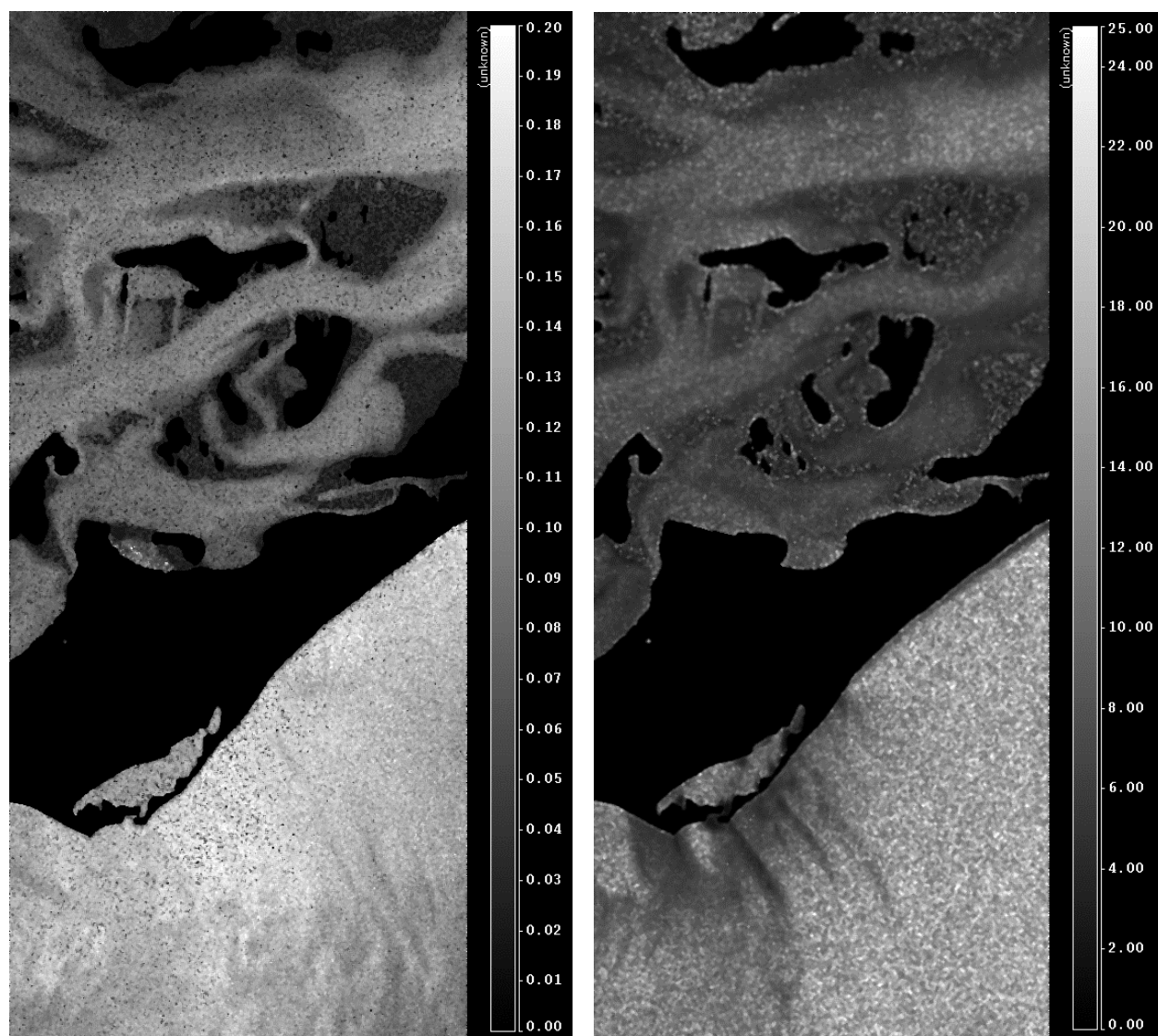

Figure 2. Bottom-albedo (left) and bathymetry (right) maps around Cayo Costa Island, Florida. Bottom albedo varied between 3% (grass) in the shallow (< 4 ft.) inshore areas and 20% (sand) for the deeper (> 10ft.) offshore (bottom). Inshore channels were sandy with intermediate albedos.

Large scale maps of water properties and bottom depth and albedo are critical in the assessment of visibility, navigability, and underwater sensor performance. In the same vein, the ability to detect algal blooms from space or aircraft-borne sensors is important to both economic and security concerns.

TRANSITIONS

Our red tide detection algorithm has been transitioned to NOAA Coastwatch.

RELATED PROJECTS

This project has a close association with the ROBOT project (Kaltenbacher et al.). ROBOT is an AUV/ROV deployed, laser-line imaging system designed to produce 3-dimensional maps of underwater surfaces (bottoms, seawalls, hulls, etc.) We are utilizing our methodologies and hardware to quantify and predict performance parameters for both the on-line and fluorescence (see RESULTS) modes of operation of the ROBOT systems well as to develop algorithms for automatic (computerized) target recognition.

We are also collecting field data regarding the structure of the underwater light field around objects (e.g. ship and seawall shadows) under various environmental conditions for the validation of the "Hybrid Modular Optical Model To Predict 2-D and 3-D Environments in Ports…" (HyMOM, ONR, Reinersman and Carder).

We are actively supporting three ONR projects headed by John Kloske, USF Center for Ocean Technology, and Scot Tripp, US Coast Guard Research and Development Center, toward utilizing our methodologies in Homeland Security. These projects include Advanced Underwater Port Security Systems and the Development and Evaluation of the Mobile Inspection Platform, first deployed on our ROSEBUD ROV. The ROV has also been used for evaluation deployments of the ISS ranging camera and Echoscope and Tritech Mini-king imaging sonars (Steve Lawrance, Subsea Technologies, Inc.) as well as the Coda Echoscope 1600 3-D Real Time acoustic sonar (Angus Ludsdin, Codaoctopus, Ltd.)

We are investigating the efficacy of different stimulation wavelength and sources in active fluorescence imagery and identification of bottom objects. This work is in conjunction with Charles Mazel, Physical Sciences, Inc.

Efforts within our group toward model inversion (funded through ONR/CoBOP and NASA) utilizing remote sensing reflectance provides bathymetry and water optical properties. Most recently, efforts have been focused on providing sea-truth and image interpretation for the PHILLS hyperspectral imaging sensor owned by NRL Washington (Curtiss Davis) and operated by Paul Bissett, Florida Evironmental Research Institute.

Finally, this project benefits from the database acquired during the ONR project Coastal Benthic Optical Properties (CoBOP, Carder and Costello) field campaigns.

REFERENCES

Note: citations above not presented here are included in our current PUBLICATIONS section below.

Costello, D.K., K.L. Carder, and J.S. Patch. 1998a. Methods for Utilizing Hyperspectral In-situ Light Profiles in the Presence of Wave Focusing and the Absence of Above-water Measurements. EOS AGU/ASLO.

Costello D.K., K. L. Carder, W. Hou, T.G. Peacock, and J.E. Ivey. 1998b. Hyperspectral Measurements of Upwelling Radiance During CoBOP: the Role of Bottom Albedo and Solar Stimulated Fluorescence. Ocean Optics XIV. Kailua-Kona.

Costello D.K. and K. L. Carder. 1997. In situ optical data collected aboard unmanned underwater vehicles in coastal water. ASLO 97. Santa Fe.

Renadette, L.A., K.L. Carder, D.K. Costello, W. Hou, and D.C. English. 1998.

Characterization of Bottom Albedo Using Landsat TM Imagery. EOS AGU/ASLO.

Renadette, L.A., K.L. Carder, D.K. Costello, and W. Hou. 1997. AUV Data: Interpretation in Terms of Aircraft and Satellite Imagery. ASLO 1997, Santa Fe.

PUBLICATIONS

Cannizaro, J.P., K.L. Carder, F.R. Chen, *C.A. Heil*, and G.A. Vargo, 2003. A novel technique for detection of the toxic dinoflagellate, *Karenia brevis*, in the Gulf of Mexico from remotely sensed ocean color data, *Cont. Shelf Res.*[accepted, refereed].

Carder, K.L.,C.C. Liu, Z. Lee, D.C. English, J.Patten, F.R. Chen, J.E. Ivey, and C. Davis. (2003). Illumination and turbidity effects on observing facetted bottom elements with uniform Lambertian albedos. *Limnol. Oceanogr.*, 48(1), 355-363. [published, refereed].

Carder, K.L., F.R. Chen, J.P. Cannizzaro, J.W. Campbell, and B.G. Mitchell. (2003). Performance of MODIS semi-analytic ocean color algorithm for chlorophyll-a. *Advances in Space Research*, [in press, refereed]

Cattrall, C., K.L. Carder, H. Gordon, and K. Thome, 2003. Columnar aerosol single-scattering albedo and phase function retrieved over the ocean by sky radiance: Measurements of Saharan dust, *J. Geophys. Res.108(D9)*: 4287. [published, refereed].

D'Sa, E.J., C. Hu, F.E. Muller-Karger and K.L. Carder. (2002). Estimation of colored dissolved organic matter and salinity fields in Case 2 waters using SeaWiFS: Examples from Florida Bay and Florida Shelf. *Proc. Indian Acad. Sci. (Earth Planet. Sci.)*, 111(3), 197-207. [published, refereed].

Hu,C. F.E. Muller-Karger, D.L. Biggs, K.L. Carder, B. Nababan, D. Nadeau, and J. Vanderbloemen, 2003. Comparison of ship and satellite bio-optical and physical properties in the Northeastern Gulf of Mexico, *Int. J.Remote Sensing 24(13)*: 2597-2612.Cattrall, C., K.L. Carder, K. Thome, and H. Gordon.

(2002). Solar-reflectance-based calibration of spectral radiometers. *Geophys. Res. Lett.*, 29(20), 1029-1033. [published, refereed].

Hu, C. and K.L. Carder. (2002). Atmospheric correction for aircraft sensors: Comment on a scheme used for CASI. *Remote Sens. Environ.,* 79, 134-137. [published, refereed].

Hu, C., F. Muller-Karger, Z. Lee, K. Carder, et al. (2002). Satellite images track "black water" event off Florida coast. *EOS Trans. Amer. Geophys. Un.*, 83(26), 281, 285. [published, refereed].

Lee, Z. P. and K. L. Carder. (2002). Effect of Spectral Band Numbers on the Retrieval of Water Column and Bottom Properties from Ocean Color Data. *Applied Optics*, 41(12), 2191-2201. [published, refereed].

Lee, Z. P., K. L. Carder and R. Arnone. (2002). Deriving Inherent Optical Water Properties From Water Color: A Multi-Band Quasi-Analytical Algorithm for optically deep waters. *Applied Optics*, 41(27), 5755-5772. [published, refereed].

Liu, C. C., K. L. Carder, R. L. Miller and J. E. Ivey. (2002). Fast and accurate model of underwater scalar irradiance**.** *Applied Optics*, 41(24), 4962-4974. [published, refereed].

Otis, D. B., K. L. Carder, D. C. English, and J. E. Ivey. (2004). CDOM transport from the Bahama Banks. *Coral Reefs.* [accepted, refereed].

Reinersman, P. N. and K. L. Carder. (2003). Hybrid Numerical Method for Solution of the Radiative Transfer Equation in One, Two, or Three Dimensions. *Applied Optics*, [submitted, refereed]

Voss, K. J., C. D. Mobley, L. K. Sundman, J. E. Ivey and C. H. Mazel. (2003). The Spectral Upwelling Radiance Distribution in Optically Shallow Waters. . *Jour. of Limnol. and Oceanogr.* 48:364-373. [published, refereed]

Cannizzaro, J. P., K. L. Carder, F. R. Chen, J. J. Walsh, Z. Lee, and C. A. Heil. 2002. A Novel Classification Technique for Detection Of Red Tide Blooms in the Gulf of Mexico. *Proceedings,Xth International Conference on Harmful Algae.* [published].

Costello, D. K. , K.L. Carder, J. Ivey. 2002. Measurement and Interpretation of Diffuse Attenuation and Reflectance in Clear, Deep-Water Environments: the Effects of Trans-spectral Phenomena. (*Ocean Optics XVI*). [published]

English, D. C., W. Hou, K. L. Carder, and D. K. Costello. 2002. Use of Unmanned Underwater Vehicles to Determine the Spatial Distribution of Reflectance and Optical Properties. (*Ocean Optics XVI*). [published]

Filippi, A. M., R. L. Miller, J. R. Jensen, R. A. Leathers, C. O. Davis, K. L. Carder, T. V.Downes, 2002, Cybernetic Statistical Learning For Hyperspectral Remote Sensing Inverse Modeling In The Coastal Ocean. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

Hou, W., K. L. Carder, and D. K. Costello. 2002. Coastal Bottom Feature Classification Using 2-D and 3-D Moment Invariants. (*Ocean Optics XVI*). [published]

Otis, D. B., K. L. Carder, D. C. English, J. E. Ivey , J. Patch, F. R. Chen, and H. Warrior, *2002,* Using Seawifs Imagery And Optical Property Measurements To Investigate The Bahama Banks As A Source Of Gelbstoff To The Surrounding Deep Ocean. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

Reinersman, P. N. and K. L. Carder, 2002, A modular, hybrid method for solving the radiative transfer equation with arbitrary geometry in 1, 2, or 3 dimensions. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

Steward, R. G. and K. L. Carder, 2002, Compression Of Autonomous Hyperspectral Data. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

Warrior, H., K. L. Carder, *Z.P.Lee*, D. Otis and R. Chen. 2002. An improved optical model for heat and salt budget estimation for general ocean circulation models. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

PATENTS

U.S. Provisional Patent entitled "3-D Imaging System" (USF ref. No. 03A024PR) filed April 1, 2003. Kaltenbaucher, Patten, Carder, Costello, and Kloske.

U.S. Provisional Patent entitled "3-D Imaging System with Pre-Test Module" (USF ref. No. 03B066) filed April 1, 2003, Carder and Reinersman.